ACCUMULATOR RING LATTICE FOR THE NATIONAL SPALLATION NEUTRON SOURCE

C.J. Gardner*, Y.Y. Lee and A.U. Luccio
Brookhaven National Laboratory, Upton, NY 11973.

Abstract

The Accumulator Ring for the proposed National Spallation Neutron Source (NSNS) [1] is to accept a 1.03 millisecond beam pulse from a 1 GeV Proton Linac at a repetition rate of 60 Hz. For each beam pulse, 10^{14} protons are to be accumulated via charge-exchange injection. A 295 nanosecond gap in the beam, maintained by an rf system, will allow for extraction to an external target for the production of neutrons by spallation. This paper describes the four-fold symmetric lattice that has been chosen for the ring. The lattice contains four long dispersion-free straight sections to accomodate injection, extraction, rf cavities, and beam scraping respectively. The four-fold symmetry allows for easy adjustment of the tunes and flexibility in the placement of correction elements, and ensures that potentially dangerous betatron structure resonances are avoided.

1 THE LATTICE

The lattice for the accumulator ring will consist of four superperiods, each containing a $90°$ arc and a long straight section [2]. The layout of the accumulator is shown in Figure 1. Each arc will consist of four identical FODO

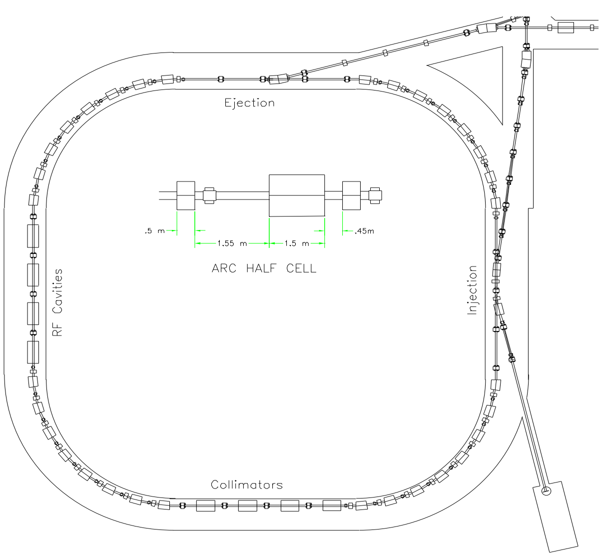

Figure 1: Accumulator ring layout.

cells and will have a total betatron phase advance of 2π which will ensure zero dispersion in the long straight sections. The arc half-cells will be 4 meters long and consist

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Table 1: NSNS Accumulator ring parameters

Kinetic Energy	1.0 GeV
Magnetic Rigidity	5.6575 T-m
Circumference	220.688 m
Periodicity	4
Structure	24 FODO
Beam Emittance	120 πmm-mrad
Ring Admittance	312 πmm-mrad
β_{max}(x/y)	19.2/19.2
X_p(max/min)	4.1/0.0 m
$\nu_{x/y}$	5.82/5.80
Natural $\xi_{x/y}$	-6.6/-7.3
γ_t	4.93

of a half-quadrupole, a 1.55 m space, a 1.5 m long dipole, a 0.45 m space, and a half-quadrupole. Two identical FODO cells without a dipole will form each long straight section. Here the half-cells will be 5.793 meters long and the phase advances will be adjusted so that the horizontal and vertical tunes of the ring are 5.82 and 5.8 respectively. The lattice functions for one superperiod are shown in Figure 2 where the plot runs from the center of one long straight section to the next. The relevant ring parameters are given in Table 1.

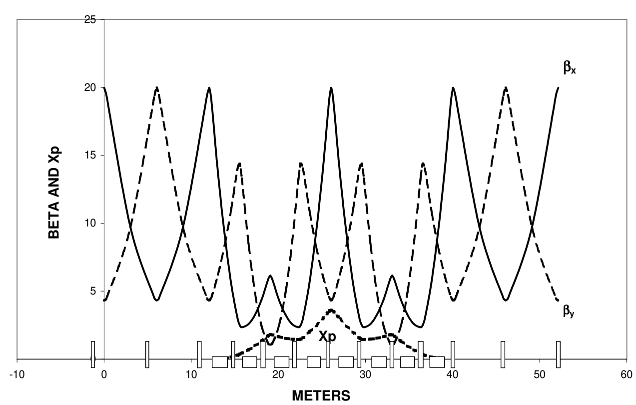

Figure 2: Accumulator lattice functions.

The four superperiods of the ring are labeled A, B, C, and D, and run sequentially along the beam direction from the beginning of one arc to the next. The order of magnets in each superperiod X is DHX1, QVX1, DHX2, QHX2, . . ., DHX8, QHX8, QVX9, QHX10, QVX11, and QHX12, where D and Q denote dipoles and quadrupoles and H and V refer to the horizontal and vertical planes. The long

Table 2: Tunability and Chromaticity Behavior.

$\Delta p/p$ %	$\Delta\nu_x$	$\Delta\nu_y$	$\beta_{x,max}$ $\beta_{y,max}$ [m]	$X_{p,max}$ $X_{p,min}$ [m]	ΔFQ ΔDQ %
0.0	0.0	0.0	19.2 19.2	4.1 0.0	0.0 0.0
0.0	-0.5	0.0	21.9 17.8	4.1 0.0	-18.1 -4.3
0.0	0.0	-0.5	17.8 21.9	4.1 0.0	-4.3 -18.1
0.0	-0.5	-0.5	20.1 20.1	4.1 0.0	-24.8 -24.8
0.5	-0.03	-0.04	19.9 19.3	4.16 -0.1	
1.0	-0.06	-0.07	20.5 19.5	4.23 -0.2	

straight section in A runs from QVA9 through QHA12 and will be used for injection. Similarly, the long straight sections in B, C, D will be used for beam scraping collimators, rf cavities, and extraction respectively. In the arcs, the 1.55 m space between a quadrupole and the downstream dipole will contain a beam position monitor (pickup electrode) followed by a correction package and a vacuum pumping port. The correction package will consist of a dipole corrector and either a skew quadrupole or higher-order multipole corrector. Position monitors and correction packages will also be located downstream of each quadrupole in the long straight sections. Other available space in the lattice will be used to accommodate tune meter kickers, a transverse damping system, and clearing electrodes, to name a few.

The beam will have a full emittance, both horizontal and vertical, of 120π mm-mrad and the ring will have a full acceptance of 312π mm-mrad, which is twice the full beam emittance plus an allowance of 1 cm for the maximum possible orbit errors. The ring must also accept a maximum beam momentum spread of $\pm 1\%$ and the quadrupoles QHX4 at the centers of the arcs will be 50% larger than the others to meet this requirement. The quadrupoles QHX10 in the centers of the long straights will also have larger apertures to allow for the injection orbit bumps and for the extraction kicker and septum displacements.

2 TUNABILITY AND CHROMATIC BEHAVIOR

It will be desirable for the accumulator ring to run with different sets of betatron tunes. Small tune changes are expected in normal ring operations, however tune changes of up to half a unit may be implemented in special operations for accelerator studies. Table 2 shows the behavior of the beta function for a tune change of 0.5 units. As can be seen in the Table, a change in tune of half a unit results in a change of less than 15% in the beta function, with no change in the dispersion function. Because the chromatic behavior is nonlinear, the betatron functions for an off-momentum particle might show significant changes, but for this lattice, even at 1% off-momentum, the maximum ever expected, the betatron functions and the dispersion behave very well.

In practice the desired tunability will be achieved by dividing the main windings of the quadrupoles into three families, with the magnets of each family connected in series to a separate power supply. The first family will consist of all 28 arc quadrupoles (QVX1, QHX2, . . ., QVX7); the second will consist of all 12 focusing quadrupoles (QHX8, QHX10 and QHX12) in the long straight sections; and the third will consist of all 8 defocusing quadrupoles (QVX9 and QVX11) in the long straights. The current in the first family will be adjusted so that the phase advance of each arc is 2π, thereby ensuring zero dispersion in the long straight sections. The currents in the second and third families will then be used to adjust the tunes. The quadrupoles will also have trim windings which will be divided into four families. These will be used for fine tuning the lattice. In particular they will allow for independent adjustment of the currents in the quadrupoles at the center (QHX10) and the ends (QHX8 and QHX12) of the long straight sections. This is important in the A superperiod, for example, where the injection setup depends on the setting of the QHA10 quadrupole.

3 CORRECTION ELEMENTS

To compensate for unavoidable field imperfections and magnet alignment errors, the accumulator ring will have a set of correction elements consisting of horizontal and vertical dipoles, skew quadrupoles, sextupoles, skew sextupoles, and octupoles. Trim windings on the lattice quadrupoles will allow for any necessary quadrupole corrections. The correction elements will be contained in packages located downstream of the position monitor at each lattice quadrupole. Each package, except those downstream of the quadrupoles QHX10 (at the centers of the long straight sections), will contain a horizontal or vertical dipole and either a skew quadrupole or higher-order multipole. The packages downstream of quadrupoles QHX10 will contain only horizontal dipoles. Thus, there will be a total of 24 horizontal and 24 vertical dipoles. Each superperiod will have four skew quadrupoles (QSX1, QSX3, QSX5, QSX7) located in the correction packages downstream of quadrupoles QVX1, QVX3, QVX5, and QVX7; two sextupoles (SHX8, SVX9) located downstream of QHX8 and QVX9; two skew sextupoles (SSVX11, SSHX12) located downstream of QVX11 and QHX12; and three octupoles (OHX2, OHX4, OHX6) located downstream of QHX2, QHX4, and QHX6.

Closed orbit correction is discussed in Ref. [3].

4 RESONANCE CORRECTION

Because the ring will operate at very high intensities for which stringent limits on losses will be imposed, the possibility of beam loss due to resonance excitation must be considered. The second, third and fourth-order resonances between tunes of 5 and 6 are shown in Figure 3. Although the space-charge tune spread of the beam is expected to be small (~ 0.1), there are a number of resonance lines sufficiently close to the working point to be of concern. Moreover, even though lines such as those excited by normal and skew quadrupoles are far from the working point, they can cause unfavorable distortions of the betatron functions. The four-fold symmetric lattice allows placement of correction elements so that either even or odd harmonics (in azimuth θ) can be produced for the correction of the following resonances. Detailed calculations are underway to determine the required magnet strengths.

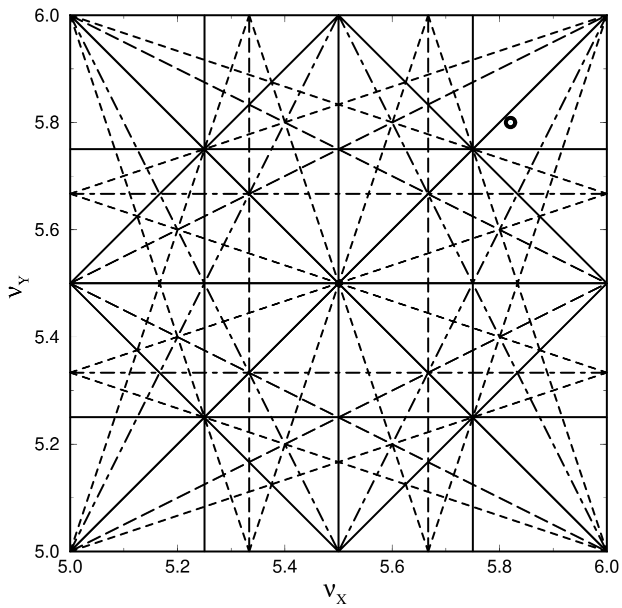

Figure 3: Accumulator Tune Chart. The circle shows the working point. Solid and short-dashed lines indicate second and fourth-order resonances; long-dashed and dot-dashed lines indicate third-order.

4.1 Second-Order Resonances

The $2\nu_x = 11$ and $2\nu_y = 11$ resonances can be corrected by exciting the trim windings on the quadrupoles with harmonic 11 in azimuth θ. (To produce an odd harmonic, magnets separated by $\theta = 180°$ are excited with equal but opposite currents.) Similarly, the sum resonance $\nu_x + \nu_y = 11$ can be corrected by exciting the skew quadrupole correctors with harmonic 11; the difference resonance $\nu_x - \nu_y = 0$ can be corrected (or enhanced if coupling between the two planes is desired) by exciting these correctors with harmonic 0.

4.2 Third-Order Resonances

The $3\nu_x = 17$ and $\nu_x + 2\nu_y = 17$ resonances can be corrected by exciting sextupoles with harmonic 17. The eight sextupole correctors allow for independent correction of the two lines. Similarly, the $3\nu_y = 17$ and $\nu_y + 2\nu_x = 17$ resonances can be corrected with the eight skew sextupole correctors.

4.3 Fourth-Order Resonances

The fourth-order resonance lines are driven by octupoles (both normal and skew) and those closest to the working point pass through the point $\nu_x = \nu_y = 5.75$ in Figure 3. The effects of these lines can be reduced by exciting the octupole correctors with harmonic 0. Schemes for correcting specific lines are under investigation. The octupole correctors also allow for Landau damping of transverse instabilities.

5 STRUCTURE RESONANCES

One consideration in our choice of a lattice was the avoidance of structure resonances. The 4-fold symmetric lattice has fourth-order structure resonances at betatron tunes of 5 and 6; third-order at tunes of 5.333 and 6.666; and second-order at a tune of 6. However, none of these are near the proposed working point. A 3-fold symmetric lattice that has been considered in previous design studies, on the other hand, has fourth-order structure resonances at a betatron tune of 3.75 which is right on top of the proposed working point for this lattice. Although these resonances may not hurt the ring performance, they are best avoided.

6 REFERENCES

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[3] C.J. Gardner, “Closed Orbit Distortion and Correction in the Four-Fold Symmetric NSNS Ring”, BNL/NSNS Tech.Note No. 031, April 14, 1997.